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The Performance of Quartzite and Natural Aggregate in Flexible Pavement : A Case Study

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THE PERFORMANCE OF QUARTZITE AND NATURAL AGGREGATE IN FLEXIBLE PAVEMENT-A CASE STUDY

BY

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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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ABSTRACT

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Two parking lots, one made of quartzite and the other made of natural aggregrate, were compared using the Marshall method mix design test, skid resistance tests, and economic studies. It was found that the pavement with quartzite uses 13.3% less asphalt, gives a higher mean skid resistance, and saves 0.13 dollars per square yard per year during the life span of the pavement assumed in this study. It was determined that quartzite pavement is preferable to pavement with natural aggregate.

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CHAPTER 1

INTRODUCTION

The flexible pavement structure in a parking lot must have enough stability to meet the load exerted from parked cars as well as the rolling action of traffic. The surface of parking pavement does not receive the same degree of compaction from the rolling action of traffic as it would under normal road usage. Therefore, the design surface, base course, and wearing course must be adequate to distribute the standing and slow moving loads over a sufficient area of sub-grade in order to prevent the surface from deforming.(1) The relative value of using quartzite and natural aggregate is considered here.

The use of quartzite and natural aggregate as construction materials for roads goes back several hundred years. The natural aggregate (gravel) was used then to make hard earth roads. At the present time quartzite and natural aggregate are used for the sub-base, the base, and the surface pavement. The surface pavement can be anything from a simple surface treatment (chip seal) to a full depth asphalt pavement.(2)

A. QUARTZITE

The New Larousse Encyclopedia of Earth Sciences defines quartzite as a "solid quartz rock produced by the cementing of sand grains with crystalline quartz. Quartzite is a smooth, fine-textured, extremely hard, glassy rock used primarily as road-stone. It is generally light in colour, white when pure and tinted gray, tan, red, or purple in its impure forms. Close examination reveals tiny, rounded quartz grains."(3)

One type of quartzite is the Sioux quartzite. The pink Sioux quartzite takes its name from outcrops along the Big Sioux River in South Dakota and Iowa. This quartzite is distributed in 11 counties in southwestern Minnesota, 25 counties in southeastern and central South Dakota, probably 2 counties in northwestern Iowa, and 1 county in northeastern Nebraska. Figure 1 shows where Sioux quartzite may be found.(4)

B. NATURAL AGGREGATE

The Glossary of Geology defines natural aggregate or gravel as "an unconsolidated, natural accumulation of rounded rock fragments resulting from erosion, consisting predominantly of particles larger than sand, such as

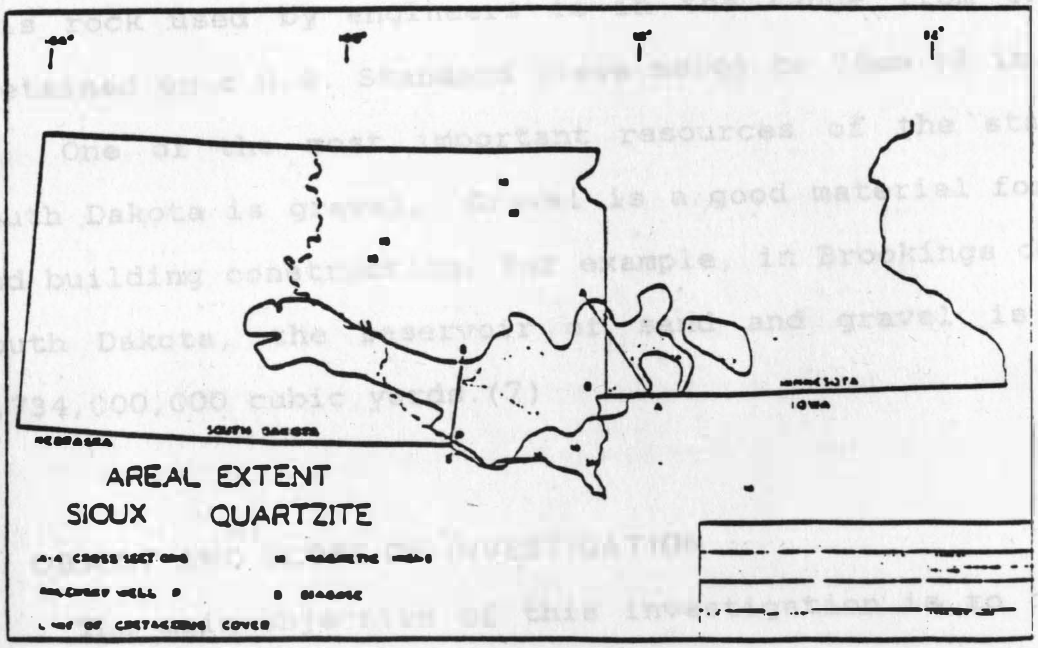


Figure 1: Areal extent of the Sioux quartzite

boulders, cobbles, pebbles, granules, or any combination of these fragments; the unconsolidated equivalent of conglomerate."(5)

The term gravel in the United States is used for rounded rock or mineral soil particles. The diameter of this rock used by engineers is in the range from 4.76 mm (retained on a U.S. Standard Sieve no.4) to 76mm (3 in.).(6)

One of the most important resources of the state of South Dakota is gravel. Gravel is a good material for road and building construction. For example, in Brookings county, South Dakota, the reservoir of sand and gravel is about 4,734,000,000 cubic yards.(7)

D. OBJECT AND SCOPE OF INVESTIGATION

The main objective of this investigation is to compare the performance of two types of flexible pavement: one hot mix pavement using quartzite aggregate, the other one using natural aggregate.

Two parking lots were constructed in the summer of 1984 on the South Dakota State University campus in Brookings, South Dakota. One parking lot, constructed in front of the Dairy-Microbiology building, used natural aggregate (gravel) in the hot mix. The other one, south of the Animal Science

Complex, used quartzite instead. Figure 2-4 shows the location of these two parking lots. These two lots will be the primary elements for research in this paper.

The comparisons of the two pavements are based on the Marshall test, the skid resistance of the surface texture, and economic analysis.

The Marshall test was done to establish the optimum asphalt content of the mixtures.

The surface textures of the two pavements were examined by measuring the skid resistance of the surfaces using the British Portable Skid Resistance Tester. The resulting data from the skid resistance tests were compared by employing the Statistical Analysis System (SAS) computer program for analysis of variance.

The economic analysis was done by taking into account the initial costs of the two pavements and the future costs, such as maintenance and overlay. A future cost value and then the equivalent annual value of the two asphalt pavements were calculated and compared.

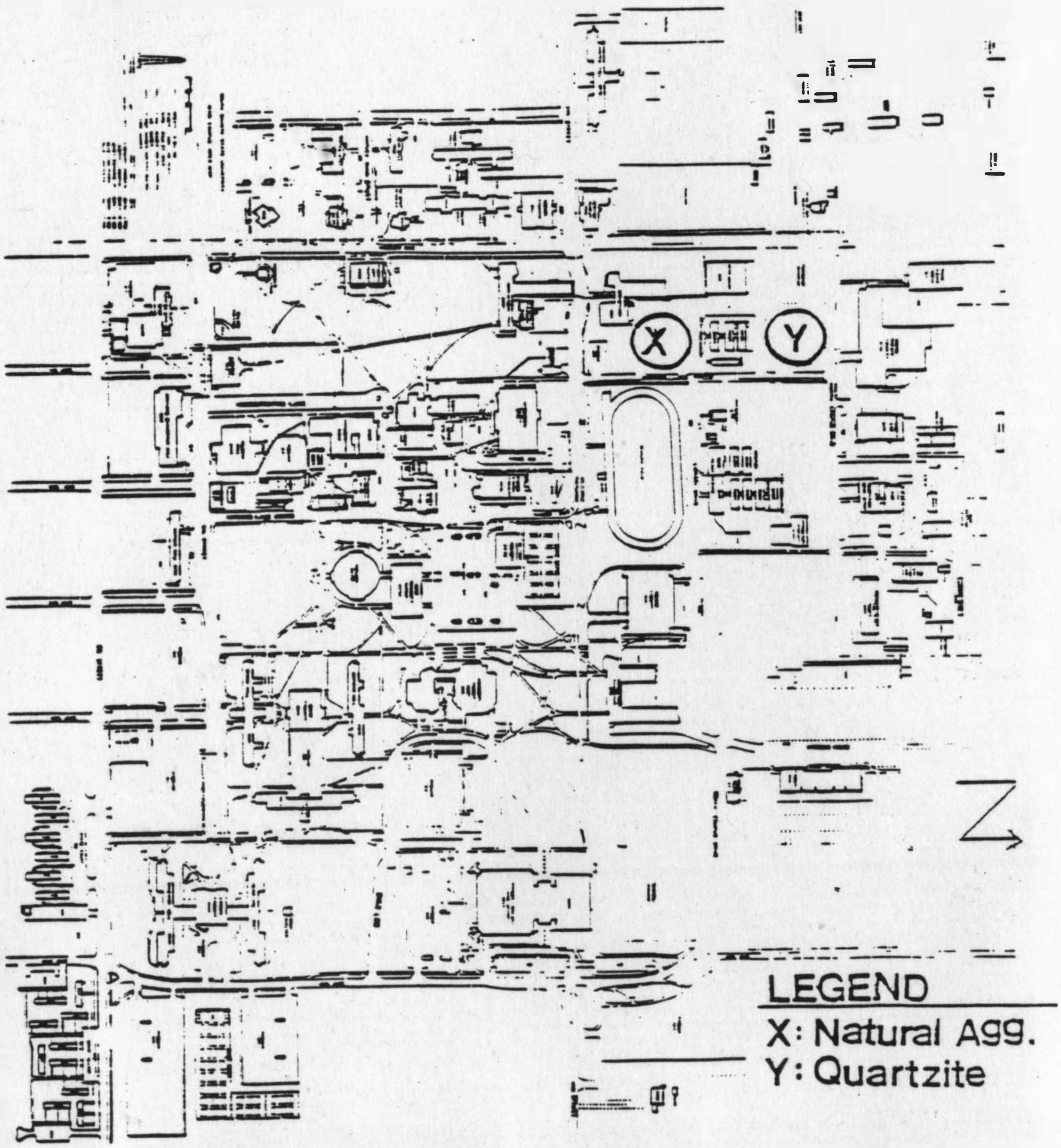


Figure 2: The location of two parking lots in South Dakota State University

Figure 3: Parking lot with natural aggregate pavement

Figure 4: Parking lot with quartzite pavement

CHAPTER 2

QUALITATIVE ASSESSMENTS OF ASPHALT HOT MIXES

One of the most common types of bituminous surface used in flexible pavements is an asphalt hot mix. Flexible pavements are composed of an aggregate (sand, gravel, or crushed stone) and a bituminous material. The structural strength of a bituminous pavement depends entirely on the aggregate, which forms the structure that carries the wheel load stresses to the base layer. The asphalt is the bonding agent among the aggregate particles, fills the voids between the aggregate particles, and waterproofs the pavement. Figure 5 shows a typical flexible pavement structure.

Plant hot mix asphalt is a mixture in which the aggregate and bituminous materials are mixed hot at a central plant. The mix is trucked hot to the job and then spread or placed on the surface hot with a paving machine and compacted immediately.

The Marshall method of mix design (ASTM D-1559) was used for the testing process of the hot-mix paving in the two parking lots mentioned in the previous chapter. The

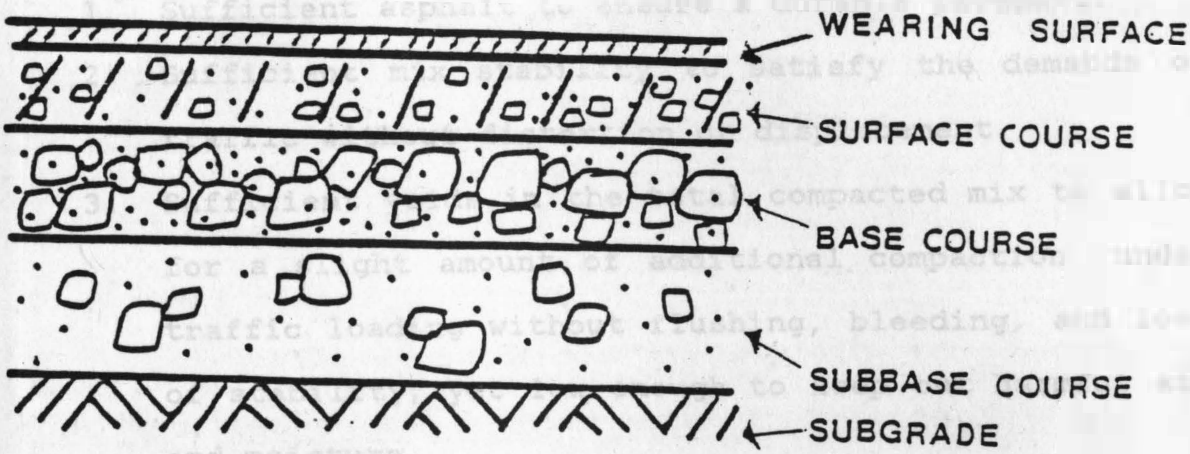


Figure 5: A typical flexible pavement

overall objective of the Marshall test is "to determine an economical blend and gradation of aggregate (within the limits of the project specifications) and asphalt that yields a mix having:

1. Sufficient asphalt to ensure a durable pavement.
2. Sufficient mix stability to satisfy the demands of traffic without distortion or displacement.
3. Sufficient voids in the total compacted mix to allow for a slight amount of additional compaction under traffic loading without flushing, bleeding, and loss of stability, yet low enough to keep out harmful air and moisture.
4. Sufficient workability to permit efficient placement of the mix without segregation."(8)

The Marshall test for the two pavements using natural aggregate and quartzite was performed in the South Dakota State University material lab. Test specimens were prepared and tested in accordance with the procedure described in The Mix Design Method for Asphalt Concrete and other Hot-Mix type, MS-2, published by the Asphalt Institute.(8)

In order to conduct a non-biased comparative study between two treatments,many variables need to remain unchanged. The following paragraphs examines some of these variables.

A. AGGREGATE GRADATION

The aggregate gradation was applied according to the requirements of Section 320, Asphalt Concrete, General and Section 323, Asphalt Concrete-Class G-type 1, of the South Dakota Department of Transportation Standard Specification for Roads and Bridges, 1977 Edition. The gradation which was selected for the job mix can be seen in table 1.

B. ASPHALT

The asphalt used for the mix was 120-150 penetration. This conforms to the requirements of Section 890, Asphalt material, of South Dakota Department of Transportation Standard of Specification for Roads and Bridges, 1977 edition.

C. ASPHALT CONTENT

Five different asphalt contents were used to produce the test samples. The asphalt contents were 5.5, 6.0, 6.5, 7.0, and 7.5 of the total weight base (TWB).

Table 1 : Aggregate gradation used in hot mixes

SIEVE SIZES	SOUTH DAKOTA CLASS G-TYPE 1 (% PASSING)	RECOMMENDED JOB MIX GRADATION (% PASSING)
3/4"	100	100
3/8"	70-90	80
NO.4	52-70	61
NO.10	32-52	42
NO.40	15-32	23
NO.200	4-10	7.0

D. MIX DESIGN

To test each asphalt content, three briquettes were made. After the test samples were made, taking into account the preceding considerations, the analysis of density-voids and stability-flow tests on the specimens was performed.

Once the density and voids of the briquettes were established, the specimens were heated to 140 F. for the Marshall stability and flow tests. The briquettes were placed in a split breaking head for these tests as seen in Figure 6.

Load was applied to the specimen at a rate of 50.8 mm (2 inches) per minute. The Marshall Stability of the specimens was then derived. The amount of movement or strain occurring between no load and the maximum load in units of 0.25 mm (0.01 inch), is the flow value of the specimen.

The data of the test were then used to establish the optimum asphalt content of the mixture. The following asphalt content was found to be optimum.

As indicated in a letter of June 4, 1984, from Dr. Ali Selim, Professor of Civil Engineering at South Dakota State University to Steve Koepsell, Engineer at the South Dakota State University Physical Plant, the "Laboratory tests conducted on the quartzite (Marshall mix design method ASTM-1559) revealed that six percent asphalt cement (6 % TWB) will be adequate when preparing the hot mix.

Figure 6: Breaking machine

Laboratory tests on natural aggregate from the Brookings area (in the summer of 1983), which was used in paving the dairy-Microbiology lot, indicated that the oil content should be six and eight tenths of one percent (6.8 % TWA)."

The result that was ascertained by employing the Marshall method of mix design was that natural aggregate requires 13.3% more asphalt than that of quartzite in order to meet the mix design specification.

CHAPTER 3

SURFACE TEXTURE AND PHYSICAL PROPERTIES

Highway traffic accidents are a major national concern. State highway and transportation departments spend large amounts of their annual budgets on accident reduction programs and on measures for minimizing injuries and damages. One of the many different causes of highway accidents is slippery pavements. Pavements are slippery when the force acting on the vehicle is not resisted by the friction force between the pavement and the tires.(9) An important factor in the safe operation of motor vehicles is the presence of friction or the skid resistance between the tire and the pavement surface.(10) Skid resistance testing provides a measure of pavement friction, which is one of the indices of pavement performance. It has been shown that accident rates increase when pavement skid resistance drops below 40 skid number (SN). However, there are many pavements with a skid resistance as low as 20 SN that have average accident rates.(11)

"The majority of highway agencies in the U.S. measure pavement skid resistance with locked wheel skid testers"(12), which is a method of measuring the skid resistance of the pavement with a specified full-scale automotive line.

This standard test is designated as E-274 by the American Society of Testing Material (ASTM).

The traffic volume on the two flexible pavements was measured by using a road tube ; while the skid resistance was measured using The British Portable Skid Resistance Tester. This device and the method of its use are found in the ASTM and designated as E303-74. The traffic volume is shown in Table 2.

The Skid Resistance Tester has a pendulum device which measures the frictional resistance of a wet surface by the passage of a wet rubber slider. The slider is spring loaded and is 3 by 11 inches. The contact with the surface for the test is made primarily by the 3 inch edge. The device can be adjusted vertically in order to control the surface touched by the rubber. After the proper adjustments are made, the pendulum and drag pointer are locked in a horizontal position, locking the pendulum to the release catch. When released the pendulum carries the drag pointer in an arc. After touching the pavement surface, the drag pointer stays at the highest point where the pendulum falls back. Wherever the drag pointer stops, the reading of the scale shows the loss in energy of the pendulum arm, which is equal to the work done against friction by the slider. The reading is designated as skid number(SN). Figure 7 shows the British Portable Skid Resistance Tester.

Table 2: Traffic volume using the two parking lots

Date	Number of vehicles	
	Quartzite Pavement	Natural aggregate pavement
Wednesday Oct.30,1984	414	380
Thursday Oct.31,1984	382	332
Friday Nov.1,1984	346	377
Saturday Nov.2,1984	69	81
Sunday Nov.3,1984	39	25
Monday Nov.4,1984	365	394
tuesday Nov.5,1984	189	372

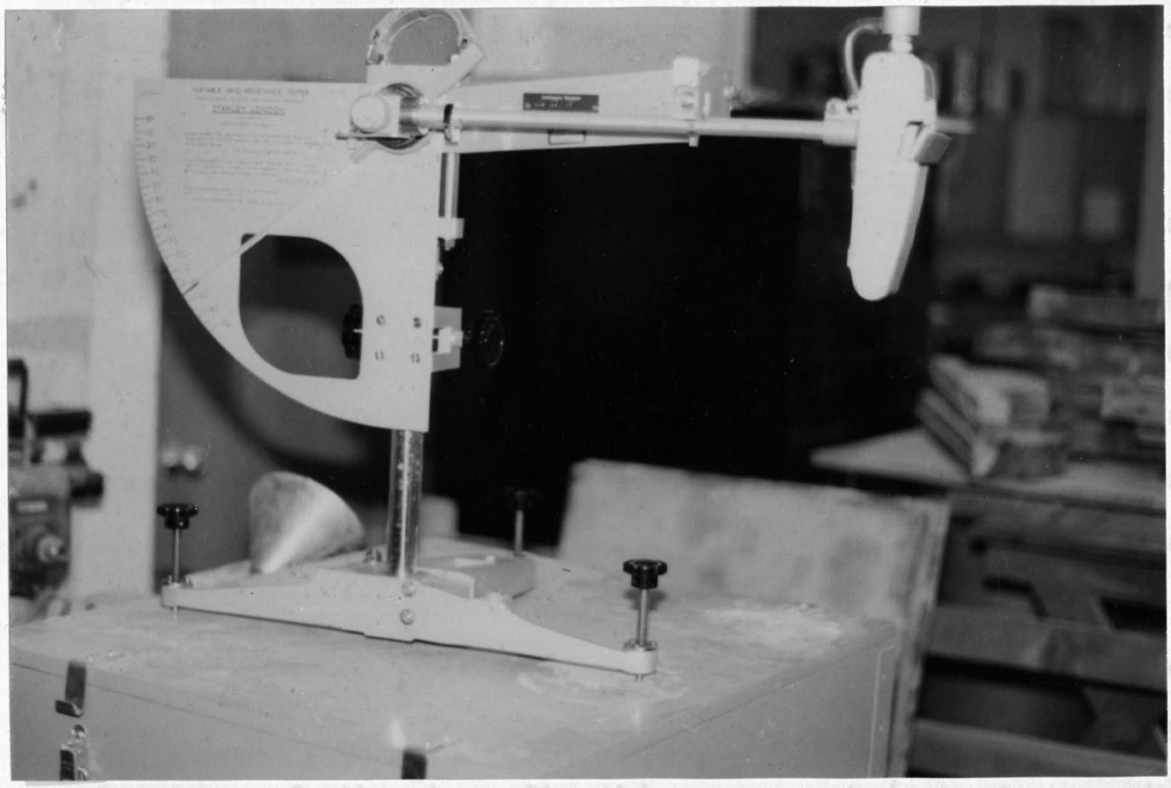


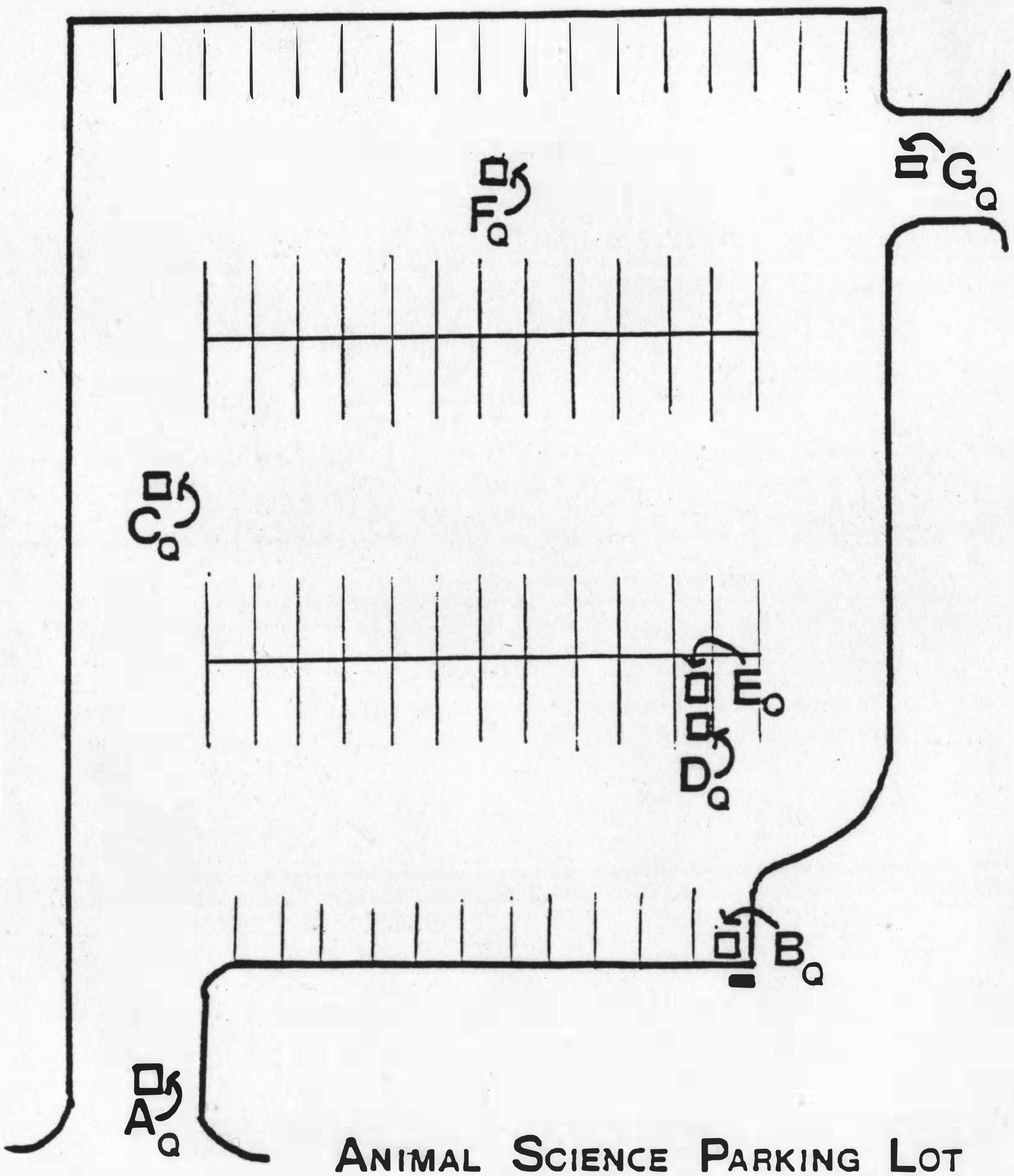
Figure 7: British pendulum tester

In order to find skid resistance, seven test location in each parking lot were selected. So that comparisons would be appropriate, similar spots in both parking lots were chosen. The following paragraphs describe the test locations, the number of test locations in each parking lot, and the designated reasons for choosing the specific test location.

Two of the test locations (1 yard by 1 yard) in each lot were established at each entrance / exit. The test locations were designated as An, Gn, Aq, and Gq, where subscript n means a pavement made of natural aggregate and subscript q stands for pavement made of quartzite. A and G represent the locations. Figures 8 through 11 illustrate the locations and the surface textures of the pavements at the specified locations. The reason for choosing these locations was to be able to analyze and compare the skid resistance of the two flexible pavements' textures where there has been much maneuvering and high traffic volume.

The other test location (1 yard by 1 yard) was chosen in the middle of each driveway of each parking lot. The test locations are designated as Cn, Fn, Cq, Fq. Figures 8, and 9 illustrate the test locations.

The reason for choosing these locations was to be able to analyze and compare the skid resistance of the specified textures in the pavement where there has been normal parking lot traffic volume.



ANIMAL SCIENCE PARKING LOT

SCALE 1": 20' - 0"

Figure 9: Location of test specimen of quartzite pavement in Animal Science parking lot

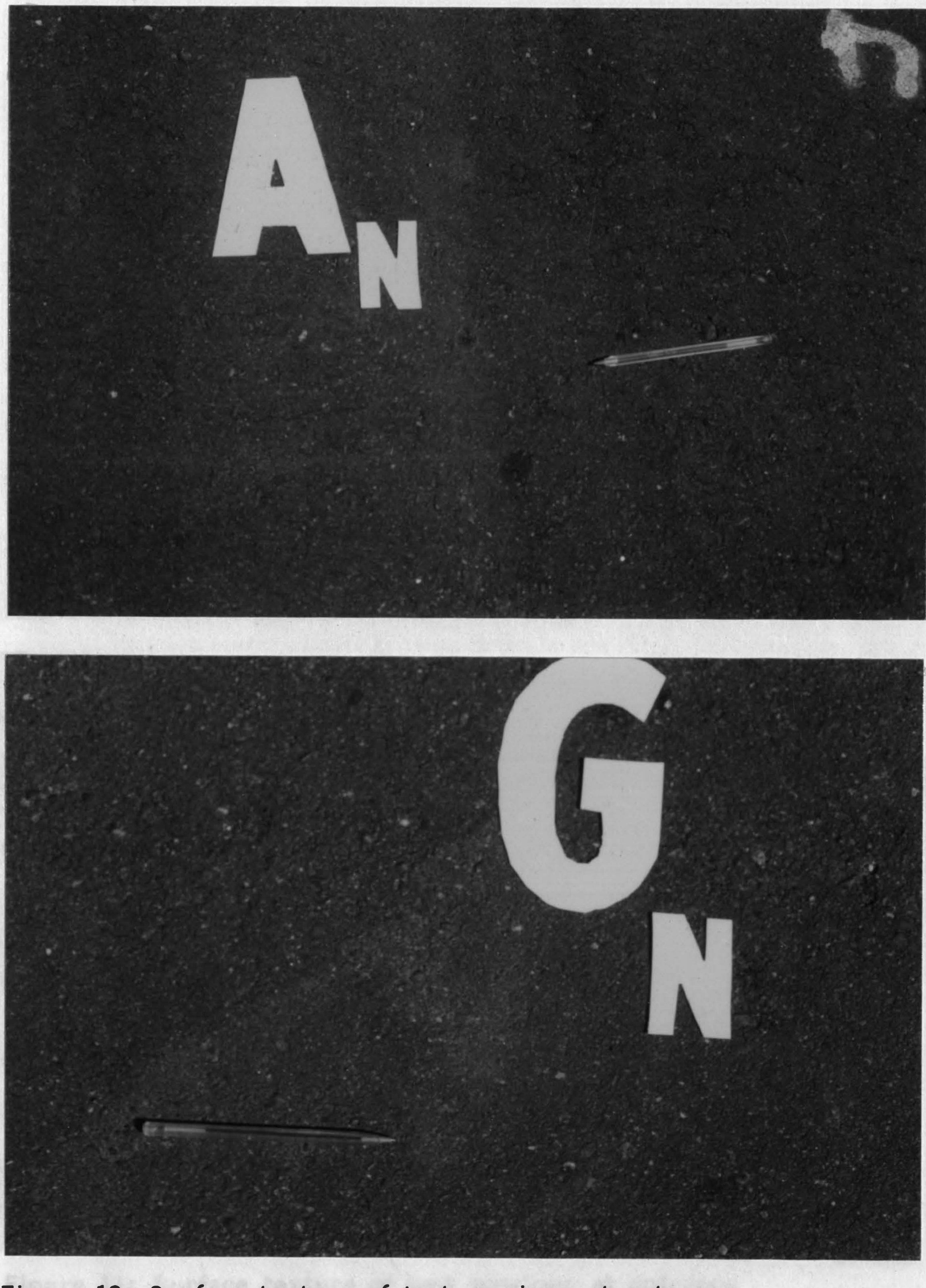


Figure 10: Surface texture of test specimen at entrance and exit of parking lot with natural aggregate pavement

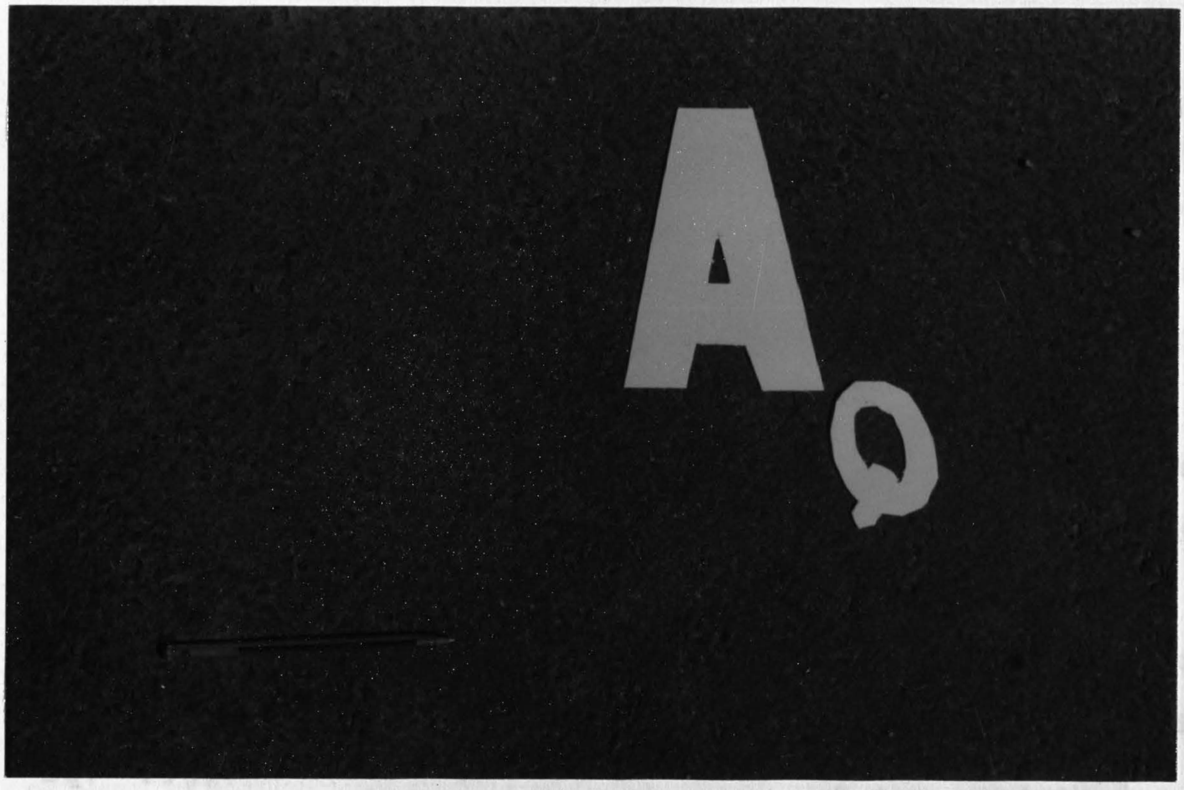


Figure 11: Surface texture of test specimen at entrance and exit of parking lot with quartzite pavement

Two test locations, each 1 yard by 1 yard, were chosen as the closest parking spaces to the building. These test locations were positioned one space between the two front wheels of the parked car and one space under the right rear wheel. These test locations are designated as Dn, En, Dq, Eq.

These locations were chosen to analyze and compare the skid resistance of surface texture of the pavement which has experienced high parking volume.

One test location was established beside the manhole in each parking lot. These test spots were designated as Bn, Bq. Figures 8 and 9 illustrate these testing locations.

The reason for choosing these locations was to analyze and compare the skid resistance of the surface texture of pavement exposed to the flow of water and traffic volume.

The test for ascertaining skid resistance was done on several different occasions. The data were then recorded. Tables 3 through 10 show the raw data of the skid numbers.

Since changes in temperature can affect the skid resistance of flexible pavements, Figure 12 was used to make corrections.(13) The temperature corrected data are also presented in Tables 3 through 10.

The data with the temperature corrections were then classified into four treatments: 1. Entrance/Exit, 2. Driveway, 3. Manhole, 4. Parking place, for the two parking

Table 3: Raw data and temperature corrected data of skid resistance from the pavement with natural aggregate

Date	Section	Surface Texture	Temperature of water on road (°C)	Correction due to Temperature	Skid-resistance (SN) Trials 1	2	3	4	Mean Trial
9/19/84	An	Medium	32.0	32 (+2)	61(63)*	64(66)*	64(66)*	65(67)*	66**
	Bn	Medium	32.0	32 (+2)	77(79)*	80(82)*	81(83)*	82(84)*	83**
	Cn	Medium	31.0	31 (+1.9)	64(65.9)*	72(73.9)*	72(73.9)*	72(73.9)*	74**
	Dn	Medium	29.0	29 (+1.7)	68(69.7)*	73(74.7)*	73(74.7)*	73(74.7)*	75**
	En	Medium	29.0	29 (+1.7)	68(69.7)*	73(74.7)*	73(74.7)*	73(74.7)*	75**
	Fn	Medium	33.0	33 (+2.5)	63(64.5)*	68(67.5)*	69(70.5)*	68(69.6)*	70**
	Gn	Medium	33.0	33 (+2.5)	60(62.5)*	63(65.5)*	64(66.5)*	63(65.5)*	66**

*temperature corrected data

**Trial mean = $\frac{66 + 66 + 67}{3}$ = 66, due to inaccuracy of the British skid resistance tester at the first trial, the first trial is not counted in calculating the mean trial.

Table 4: Raw data and temperature corrected data of skid resistance from the pavement with natural aggregate

Date	Section	Surface Texture	Temperature of water on road (°C)	Correction due to Temperature	Skid-resistance (SN) Trials 1	2	3	4	Mean Trial
9/29/84	An	Medium	20.0	20 (0)	65(65)*	70(70)*	71(71)*	72(72)*	71**
	Bn	Medium	20.0	20 (0)	79(79)*	80(80)*	80(80)*	80(80)*	80**
	Cn	Medium	20.0	20 (0)	69(69)*	71(71)*	72(72)*	72(72)*	72**
	Dn	Medium	22.0	22 (+0.3)	75(75)*	76(76)*	77(77)*	77(77)*	77**
	En	Medium	22.0	22 (+0.3)	73(73)*	74(74.3)*	75(75.3)*	74(74.3)*	75**
	Fn	Medium	22.0	22 (+0.3)	65(65)*	70(70.3)*	70(70.3)*	71(71.3)*	71**
	Gn	Medium	20.0	20 (0)	60(60)*	64(64)*	64(64)*	64(64)*	64**

*temperature corrected data

**Trial mean = $\frac{70 + 71 + 72}{3}$ = 71, due to inaccuracy of the British skid resistance tester at the first trial, the first trial is not counted in calculating the mean trial.

Table 5: Raw data and temperature corrected data of skid resistance from the pavement with natural aggregate

Date	Section	Surface Texture	Temperature of water on road (°C)	Correction due to Temperature	Skid-resistance (SN) Trials 1	2	3	4	Mean Trial
10/9/84	An	Medium	19.0	19 (0)	70(70)*	75(75)*	75(75)*	75(75)*	75**
	Bn	Medium	20.0	20 (0)	80(80)*	79(79)*	80(80)*	80(80)*	80
	Cn	Medium	18.0	18 (-0.3)	75(75)*	76(75.7)*	77(76.7)*	77(76.7)*	76
	Dn	Medium	18.0	18 (-0.3)	74(74)*	77(77)*	77(77)*	77(77)*	77
	En	Medium	18.0	18 (-0.3)	70(70)*	73(73)*	74(74)*	75(75)*	74
	Fn	Medium	18.0	18 (-0.3)	74(74)*	74(74)*	74(74)*	74(74)*	74
	Gn	Medium	15.0	15 (-1.5)	70(70)*	69(67.5)*	70(68.5)*	69(67.5)	68

*temperature corrected data

**Trial mean = $\frac{75 + 75 + 75}{3}$ = 75, due to inaccuracy of the British skid resistance tester at the first trial, the first trial is not counted in calculating the mean trial.

Table 6: Raw data and temperature corrected data of skid resistance from the pavement with natural aggregate

Date	Section	Surface Texture	Temperature of water on road (°C)	Correction due to Temperature	Skid-resistance (SN) Trials 1	2	3	4	Mean Trial
10/13/84	An	Medium	20.0	20 (0)	67(67)*	69(69)*	70(70)*	70(70)*	70**
	Bn	Medium	20.0	20 (0)	77(77)*	79(79)*	79(79)*	79(79)*	79**
	Cn	Medium	20.0	20 (0)	72(72)*	71(71)*	72(72)*	72(72)*	72**
	Dn	Medium	20.0	20 (0)	71(71)*	72(72)*	71(71)*	72(72)*	72**
	En	Medium	20.0	20 (0)	69(69)*	70(70)*	70(70)*	70(70)*	70**
	Fn	Medium	20.0	20 (0)	70(70)*	72(72)*	73(73)*	72(72)*	72**
	Gn	Medium	20.0	20 (0)	64(64)*	67(67)*	67(67)*	67(67)*	67**

*temperature corrected data

** Trial mean = $\frac{69 + 70 + 70}{3}$ = 70, due to inaccuracy of the British skid resistance tester at the first trial, the first trial is not counted in calculating the mean trial.

Table 7: Raw data and temperature corrected data of skid resistance from the pavement with quartzite

Date	Section	Surface Texture	Temperature of water on road (°C)	Correction due to Temperature	Skid-resistance (SN) Trials 1	2	3	4	Mean Trial
9/28/1984	Aq	Medium	16.0	16 (-1)	74(73)*	78(77)*	79(78)*	80(79)*	78**
	Bq	Hard	12.0	12 (-2.2)	87(85)*	88(86)*	88(86)*	88(86)*	86
	Cq	Medium	17.0	17 (-1)	74(73)*	77(76)*	78(77)*	78(77)*	77
	Dq	Medium	12.0	12 (-2.2)	69(67)*	76(74)*	76(74)*	76(74)*	74
	Eq	Medium	12.0	12 (-2.2)	80(78)*	77(75)*	77(75)*	77(75)*	75
	Fq	Medium	18.0	18 (-0.3)	72(72)*	74(74)*	75(75)*	75(75)*	75
	Gq	Medium	12.0	18 (-0.3)	75(73)*	80(78)*	80(78)*	80(78)*	78

*temperature corrected data

** Trial mean = $\frac{77 + 78 + 79}{3}$ = 78, due to inaccuracy of the British skid resistance tester at the first trial, the first trial is not counted in calculating the mean trial.

Table 8: Raw data and temperature corrected data of skid resistance from the pavement with quartzite

Date	Section	Surface Texture	Temperature of water on road (°C)	Correction due to Temperature	Skid-resistance (SN) Trials 1	2	3	4	Mean Trial
9/29/84	Aq	Medium	20.0	20 (0)	77(77)*	78(78)*	78(78)*	78(78)*	78**
	Bq	Hard	17.0	17 (-1)	85(84)*	85(84)*	85(85)*	85(84)*	84**
	Cq	Medium	20.0	20 (0)	74(74)*	74(74)*	73(73)*	73(73)*	73**
	Dq	Medium	18.0	18 (-0.3)	72(72)*	74(74)*	74(74)*	75(75)*	74**
	Eq	Medium	18.0	18 (-.03)	70(70)*	72(72)*	73(73)*	72(72)*	72**
	Fq	Medium	20.0	20 (0)	75(75)*	76(76)*	76(76)*	76(76)*	76**
	Gq	Medium	18.0	18 (-0.3)	76(76)*	77(77)*	77(77)*	77(77)*	77**

*temperature corrected data

** Trial mean = $\frac{78 + 78 + 78}{3}$ = 78, due to inaccuracy of the British skid resistance tester at the first trial, the first trial is not counted in calculating the mean trial.

Table 9: Raw data and temperature corrected data of skid resistance from the pavement with quartzite

Date	Section	Surface Texture	Temperature of water on road (°C)	Correction due to Temperature	Skid-resistance (SN) Trials 1	2	3	4	Mean Trial
10/9/84	Aq	Medium	19.0	19 (0)	73(73)*	73(73)*	73(73)*	73(73)*	73**
	Bq	Hard	19.0	19 (0)	80(80)*	79(79)*	79(79)*	79(79)*	79
	Cq	Medium	19.0	19 (0)	80(80)*	81(81)*	80(80)*	80(80)*	80
	Dq	Medium	19.0	19 (0)	75(75)*	76(76)*	75(75)*	75(75)*	75
	Eq	Medium	19.0	19 (0)	82(82)*	82(82)*	82(82)*	82(82)*	82
	Fq	Medium	19.0	19 (0)	75(75)*	76(76)*	75(75)*	75(75)*	75
	Gq	Medium	19.0	19 (0)	75(75)*	75(75)*	75(75)*	75(75)*	75

*temperature corrected data

**Trial mean = $\frac{73 + 73 + 73}{3}$ = 73, due to inaccuracy of the British skid resistance tester at the first trial, the first trial is not counted in calculating the mean trial.

Table 10: Raw data and temperature corrected data of skid resistance from the pavement with quartzite

Date	Section	Surface Texture	Temperature of water on road (°C)	Correction due to Temperature	Skid-resistance (SN) Trials 1	2	3	4	Mean Trial
10/13/84	Aq	Medium	20.0	20 (0)	77(77)*	77(77)*	77(77)*	77(77)*	77**
	Bq	Hard	20.0	20 (0)	74(74)*	77(77)*	76(76)*	77(77)*	77
	Cq	Medium	20.0	20 (0)	76(76)*	76(76)*	76(76)*	76(76)*	76
	Dq	Medium	20.0	20 (0)	74(74)*	75(75)*	74(74)*	75(75)*	75
	Eq	Medium	20.0	20 (0)	69(69)*	70(70)*	70(70)*	69(69)*	70
	Fq	Medium	20.0	20 (0)	68(68)*	70(70)*	69(69)*	69(69)*	70
	Gq	Medium	20.0	20 (0)	64(64)*	65(65)*	66(66)*	66(66)*	66

*temperature corrected data

**Trial mean = $\frac{77 + 77 + 77}{3}$ = 77, due to inaccuracy of the British skid resistance tester at the first trial, the first trial is not counted in calculating the mean trial.

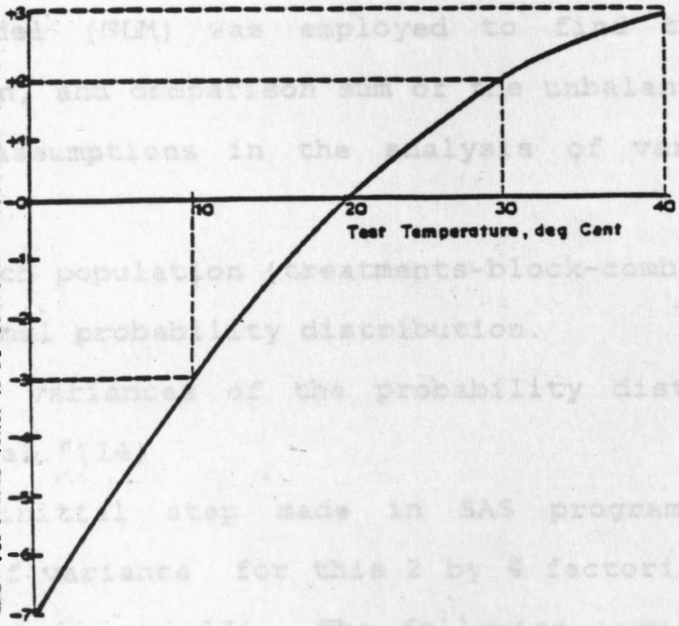


Figure 12: Suggested temperature corrections for skid resistance values to allow for changes in resistance of the slider rubber

lot pavements which use natural aggregate (N) or quartzite (Q).

The experiment was conducted using a two by four factorial design. For more information examine table 11.

The data were analyzed using a standard package in the Statistical Analysis System (SAS). The procedure of General Linear Model (GLM) was employed to find the treatment, interaction, and comparison sum of the unbalanced data.

The assumptions in the analysis of variance are as follows:

1. "Each population (treatments-block-combination) has a normal probability distribution.
2. The variances of the probability distributions are equal."(14)

The initial step made in SAS programming was the analysis of variance for this 2 by 4 factorial experiment. (See Tables 12 and 13). The following were hypothesized and these results were achieved.

1. When considering the four treatments,

Ho: M1=M2=M3=M4,

Ha: at least two treatment means differ.

Since $F>F^{3}_{3}$ 0.01, the null hypothesis was rejected in favor of the alternative hypothesis. The conclusion is that at least two treatment (skid resistance at different places) means differ.

Table 11 : Summary of temperature corrected skid resistance data

Treatment / Block	Entrance /Exit (A,G)	Driveway (C,F)	Manhole (B)	Parking place (E,D)
Lot N natural aggregate	66	77	83	75
	66	70	80	75
	71	72	80	75
	64	71	79	77
	75	76		74
	68	74		77
	70	72		70
	67	72		72
Lot Q quartzite	78	77	86	75
	78	75	86	75
	78	73	79	72
	77	76	77	74
	73	80		82
	75	75		75
	77	76		70
	66	70		75

Table 12 : Class level information for general linear model procedure

ROGHANI

CLASS	LEVEL	VALUES
TRT	4	1 2 3 4
LOT	2	1 2 - -

NUMBER OF OBSERVATION IN DATA SET = 56

Table 13 : The analysis of variance

General Linear Models Procedure

Dependent Variable: Skid Resistance Value

Source	d.f.	Type III S.S.	M.S.	F Value	PR>F
Trt	3	458.62	152.87	15.40	0.0001
Lot	1	92.45	92.45	9.31	0.0037
Lot*Trt	3	98.80	32.93	3.32	0.0275
Error	48	476.50	9.92		
Total	55				

2. When considering the two parking lots,

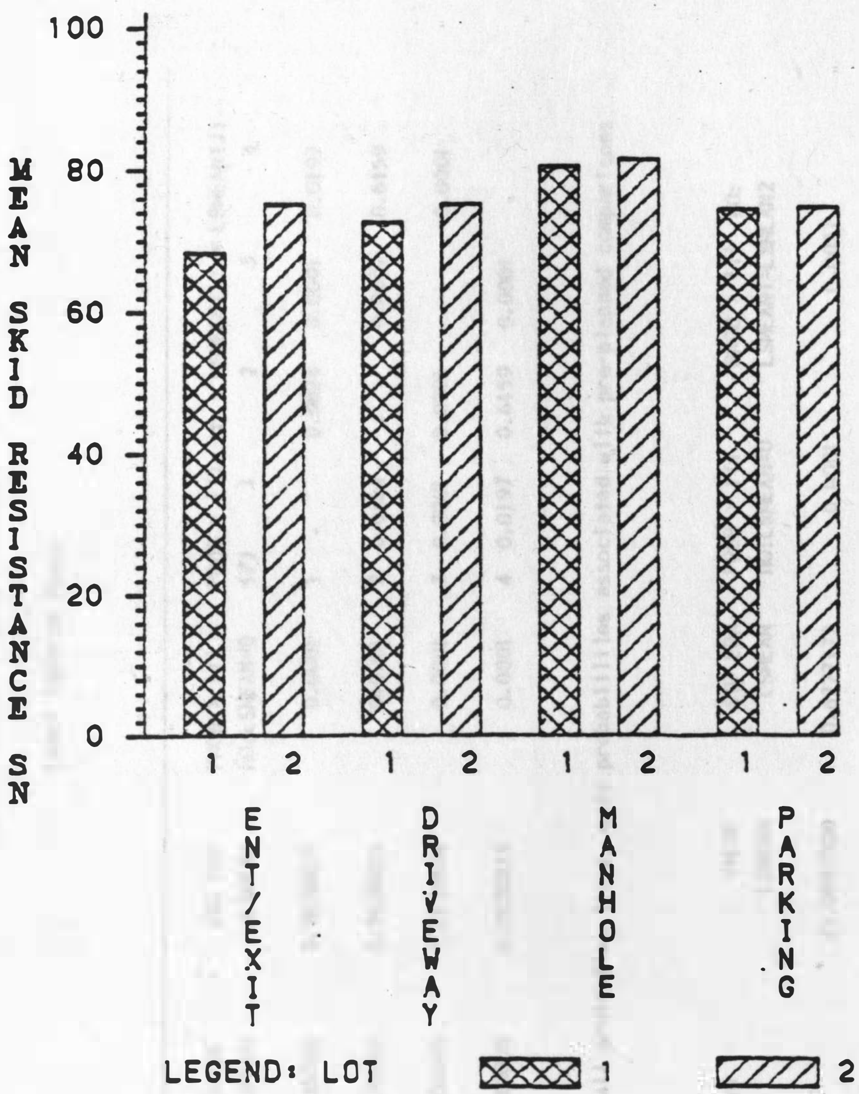
$Ho: Mn = Mq$,

HA: at least two block means differ.

Since $F > F^{1}_{3\,\alpha}$ null hypothesis was rejected in favor of the alternative hypothesis and at the α=0.037% level, it was concluded that there is a difference between the two block means. In other words, there is a highly significant difference between the mean skid resistance in the parking lot with quartzite and the lot with natural aggregate.

There is a significant interaction between the factors of lot and treatment. Obviously, the parking lot surface and the skid resistance in different locations of are not independent of one another. Figure 13 depicts this significant interaction. The mean skid number at the entrance / exit of the parking lot with quartzite was highly significantly greater than the mean skid number at the entrance / exit in the parking lot with natural aggregate. At driveway, manhole and parking places, the mean skid number was higher, although not significantly, for the parking lot with quartzite than for the parking lot with natural aggregate.

The next step of SAS programming was to compare all possible treatment means with each other. See Tables 14 and 15. The following results were established. The only matching locations which had highly significant differences



LOT 1 – NATURAL AGGREGATE
LOT 2 -- QUARTZITE

Figure 13: Interaction graph

Table 14: Comparison of treatment mean result

General Linear Models Procedure

Least Squares Means

TRT	VALUE LSMEAN	STD ERR LSMEAN	PROB > ITI HO:LSMEAN=0	PROB > ITI I/J	HO : LSMEAN(I) = LSMEAN(J) 1	2	3	4
1	71.8125000	0.7876819	0.0001	1	.	0.0624	0.0001	0.0197
2	73.9375000	0.7876819	0.0001	2	0.0624	.	0.0001	0.6159
3	81.0000000	1.1139504	0.0001	3	0.0001	0.0001	.	0.0001
4	74.5000000	0.7876819	0.0001	4	0.0197	0.6159	0.0001	.

Note: To ensure overall protection level, only probabilities associated with pre-planned comparisons should be used.

Lot	VALUE LSMEAN	STD ERR LSMEAN	PROB > ITI HO:LSMEAN=0	PROB > ITI HO: LSMEAN1=LSMEAN2
1	73.9687500	0.6227172	0.0001	0.0037
2	76.6562500	0.6227172	0.0001	

Table 15: Comparison of treatment mean result

TRT	LOT	VALUE LSMEAN	STD ERR LSMEAN	PROB > |T| HO:LSMEAN=0	PROB > |T| HO: LSMEAN(I)=LSMEAN(J) I/J	1	2	3	4	5	6	7	8
1	1	68.37	1.1139	0.0001	1	.	0.0001	0.0096	0.0001	0.0001	0.0001	0.0004	0.0002
1	2	75.25	1.1139	0.0001	2	0.0001	.	0.1022	1.0000	0.0090	0.0022	0.5812	0.6933
2	1	72.62	1.1139	0.0001	3	0.0096	0.1022	.	0.1022	0.0002	0.0001	0.2722	0.2104
2	2	75.25	1.1139	0.0001	4	0.0001	1.0000	0.1022	.	0.0090	0.0022	0.5812	0.6933
3	1	80.50	1.5753	0.0001	5	0.0001	0.0090	0.0002	0.0090	.	0.6556	0.0026	0.0038
3	2	81.50	1.5753	0.0001	6	0.0001	0.0022	0.0001	0.0022	0.6556	.	0.0006	0.0008
4	1	74.37	1.1139	0.0001	7	0.0004	0.5812	0.2722	0.5812	0.0026	0.0006	.	0.8746
4	2	74.62	1.1139	0.0001	8	0.0002	0.6933	0.2104	0.6933	0.0038	0.0038	0.8746	.

Note: To ensure overall protection level, only probabilities associated with pre-planned comparisons should be used.

between the mean skid numbers were the entrance / exits. Even though the mean skid number in the parking lot with quartzite was consistently higher than in the parking lot with natural aggregate, these apparent differences were not statistically significant.

Because of the preceding findings it may be inferred that since the entrance / exits have a higher traffic volume and necessitate more maneuvering than any of the other locations in the parking lot, the surface texture of the pavement here tends to wear faster than at the other locations in the parking lot. It may be that as time goes on the accumulated wear on the surface texture of the pavement in the other locations would lead to higher skid numbers for pavement with quartzite than that with natural aggregate. This conclusion is, of course, not within the scope of the present study.

There have been other studies done in this particular area. Mahone (15), among other researchers, has investigated the relation between skid numbers and the accumulated traffic volume in millions of vehicles. Polishing susceptible aggregate through two million vehicle passes resulted in a skid number drop from about 55 down to 40. On the other hand, when polished resistance aggregates like quartzite were used in wearing courses, the initial skid number of about 65 dropped to 40, after over 25 million vehicle passes. Therefore, hard rock is highly recommended in heavy traffic roads and low traffic parking lots.

The State of Minnesota provided similar data to that obtained from South Dakota concerning the skid number of quartzite pavement and natural aggregate. Table 16 shows the data provided by the State of Minnesota. After examining all these factors it could concluded that a pavement with quartzite is safer and stronger than a pavement with natural aggregate.

Table 16 : Skid number data on Minnesota highway network

AGGREGATE TYPE	TEST SPEED (MILES PER HOUR)	AVERAGE SKID NUMBER (SN)
Quartzite	40	56
Quartzite	55	50
Natural Aggregate	40	47
(MN/DOT Class D)	55	43

CHAPTER 4

ECONOMIC STUDIES

"The aim of an economic evaluation, and of economic choice in general, is the maximization of utility subject to a number of political and economic constraints. The term 'utility' denotes the satisfaction which a society or private firm derives from achieving a given set of objectives, while the term 'constraints' denotes the limited (scarce) resources available for achieving these objectives. It follows that the economic principles associated with the planning of public transport facilities are:

1. to define the overall objective of national transport policy
2. to establish the major resource constraints within which a planning solution must be found.
3. to generate a set of alternative planning solutions from which the most 'efficient' project can be selected. Efficiency, in this context, refers to the least costly combination of scarce resources which maximizes the achievement of the planning objectives."(16)

In order to find the best pavement, the designer should take the following into consideration:

1. Cost
2. Performance
3. Availability of pavement's materials
4. Cost of material transportation

A typical parking lot construction consists of several elements such as pavement, marking, lighting, curb and gutter, and etc.

The cost of the pavement construction is the highest of all elements in parking lot construction. The designer of the parking lot should, therefore, design an economical pavement which is durable and will fulfill the requirements for which it is constructed. In South Dakota, abundant Sioux quartzite and natural aggregate are available due to its geographical location. This provides an easy access to both the materials that are necessary for pavement construction.

The cost of material transportation plays an important part in designing an economical pavement. Since Sioux quartzite and natural aggregate are both available in South Dakota, the transportation cost of this material will be substantially less for both aggregate, but especially for natural aggregate.

Hot mix is an asphalt mix composed of aggregate and asphalt , in which the two materials have to be mixed hot, transported to the site, placed and compacted while still hot. The aggregate content of of any hot mixes is 90% to 95% by weight and 75% to 85% by volume. Therefore, the cost of aggregate, and its hauling cost have to be given attention in the economic study.

Although Sioux quartzite is almost twice as costly as natural aggregate, the quartzite is more economical to use. Studies have indicated that pavement with natural aggregate has less initial cost, but in the long run it is more costly than the pavement with quartzite because of its higher maintenance cost during the pavement's life span (2).

This study compares the economic analysis for quartzite pavement as opposed to natural aggregate pavement in a parking lot.

A. THE ECONOMIC ANALYSIS

This experiment included a comparative analysis of two pavements, one pavement consisting of natural aggregate and the other one of quartzite. A section of asphalt pavement one square yard in size, four inches thick was considered in both cases. By using the Marshall Mix Design (see chapter 2), the following results were achieved. For natural aggregate mixes, the asphalt content should be 6.8% total weight base (TWB). For quartzite mix, the asphalt content was found to be 6% TWB.

The variables that have had a major effect in the result of the comparative analysis, which will be further discussed in later paragraphs, are as follows;

Y1=Rate of inflation (in percent/year)

Y2=Interest rate (in percent/year)

Y3=Maintenance cost of natural aggregate pavement (Dollars/square yard/five years)

Y4=Maintenance cost of quartzite pavement (Dollars/square yard/eight years)

Y5=Cost of natural aggregate pavement to be overlaid (Dollars/square yard)

Y6=Cost of quartzite pavement to be overlaid (Dollars/square yard)

P1=The price of asphalt pavement with natural aggregate (Dollars/ton)

P2=The price of asphalt pavement with quartzite (Dollars/ton)

C1=Cost of asphalt pavement with natural aggregate in place (Dollars/square yard)

C2=Cost of asphalt pavement with quartzite in place (Dollar/square yard)

According to the S.D.S.U. Physical Plant, the price of asphalt pavement with natural aggregate is 32 dollars/ton (P1), while the price of asphalt pavement with quartzite (P2), is 40 dollars/ton. Each of these prices includes the cost of the aggregate, its transportation cost, fuel cost for heating it in the drum dryer, cost of hauling the hot mix to the site, and cost the of asphalt cement.

The rate of inflation (Y1) has been not steady in the 1980's and has ranged between 3.0 and 13.5 percent.(17) Since the South Dakota Department of Transportation uses a rate of inflation of 7.5 percent (18) in its economic analysis, the same figure was used in this economic study.

The average interest rate on municipal bonds was 11.56% in 1982, 9.52% in 1983, and 10.12% in 1984. Therefore, an interest rate (Y2) of 10% was used in this analysis as representative of market conditions in the early 1980's (19).

The variables Y3 and Y4 represent the maintenance cost of natural aggregate pavement and quartzite respectively. The general principle of pavement maintenance is to prevent noticeable wear rather than to neglect minor flaws and then repair serious damages. Effective maintenance increases the life of the pavement, increases traffic comfort and reduces the cost of traffic operation. The maintenance of flexible pavement includes patching, filling ruts, removing surface corrugations, pouring cracks and blading surfaces.

According to statistician Robert Leech of the South Dakota Department of Transportation, the pavements with natural aggregate, in parking lots, must be maintained every five years. Pavements with quartzite, in parking lots, need maintenance every eight years. The average cost of maintenance for both pavements is 3 dollars per square yard. This information was used for the economic analysis.

The variables Y5 and Y6 represent the cost of overlaying the pavement with natural aggregate and quartzite respectively. The purpose of the pavement overlay is to restore the pavement. An overlay may be applied over a pavement that can no longer be maintained satisfactorily. Leech also indicated that the parking lot pavement with natural aggregate is overlaid on the average of every 15 years after the initial construction, at a cost of 6 dollars per square yard. The parking lot pavement with quartzite is, on the average, overlaid every 16 years after the initial construction at the same cost.

In order to be able to compare the cost (dollars/ square yard) of the pavements in the parking lot, the cost during the life span of each pavement was analyzed. Leech indicated that the life span of a parking lot pavement with natural aggregate is twenty five years. On the other hand, the pavement in a parking lot with quartzite is twenty eight years. The following economic analysis was drawn from these factors:

PROBLEM

Given:

Y1= 7.5%

Y2= 10.0%

Y3= 3 Dollars/ square yard/ five years

Y4= 3 Dollars/ square yard/ eight years

Y5= 6 Dollars/ square yard

Y6= 6 Dollars/ square yard

P1= 32 Dollars/ton

P2= 40 Dollars/ton

In order to convert the cost to dollars per square yard, for an asphalt mat four (4) inches thick,the following calculation must be done:

Laboratory tests on both mixes revealed that the bulk specific gravity was very close; therefore, a value of BSG = 2.353 is used in this analysis (see chapter 2). From this value the Unit weight of mixes=2.353*62.4= 146.8 pound per cubic feet

Cost/sq. yard=price/ton*lbs/cu.ft.*ton/lbs.*thickness/ft *sq. ft./sq. yard

C1=Natural aggregate cost/sq. yard=32 * 146.8 * 1/2000 * 4/12 * 9

=7.04 Dollars/square yard

C2=Quartzite cost/sq. yard=40 * 146.8 * 1/2000 * 4/12 * 9

=8.80 Dollar/sq. yard

Figure 14 shows the initial cost, maintenance cost, and overlay cost for the two pavements.

It should be noted that the maintenance cost and the overlay cost for the two pavements are kept at a constant rate of three and six dollars per square yard respectively.

Taking into consideration the mentioned variables, the future value and Equivalent Annual Value (20) for hot mixes (dollars/sq. yard) using natural aggregate is as follows:

FVNA = Future value of natural aggregate surface

$$= C1\,(1+I)^{n} + \Sigma\, Y3\,(1+I)^{b} + Y5\,(1+I)^{d}$$

where n=25   where b=5,15,20   where d=15

where I = Real interest rate = Y2-Y1 = .1-.075 = .025

$$FVNA=7.04(1+.025)^{25} + 3(1+.025)^{20} + 3(1+.025)^{15} + 3(1+.025)^{5}$$

$$+ 6(1+.025)^{10}= 33.39 \text{ Dollars/Sq. Yard}$$

FVNA= AEC * CVIFA (I,n)

Where AEC= Annual Equivalent of cost

I= Real rate of interest = Y2-Y1 = .1-.075 = .025

n= Life span of natural aggregate pavement =25

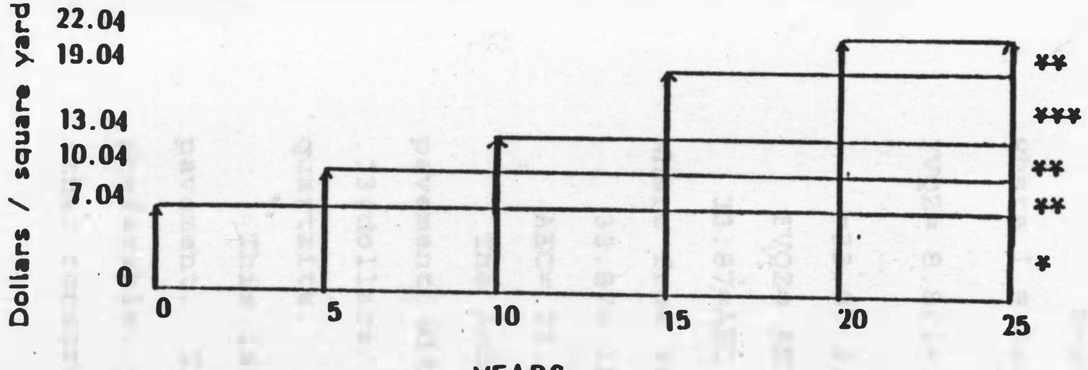
CVIFA= Compound factor from table XXI (21)

33.39=AEC * CVIFA (.025,25)

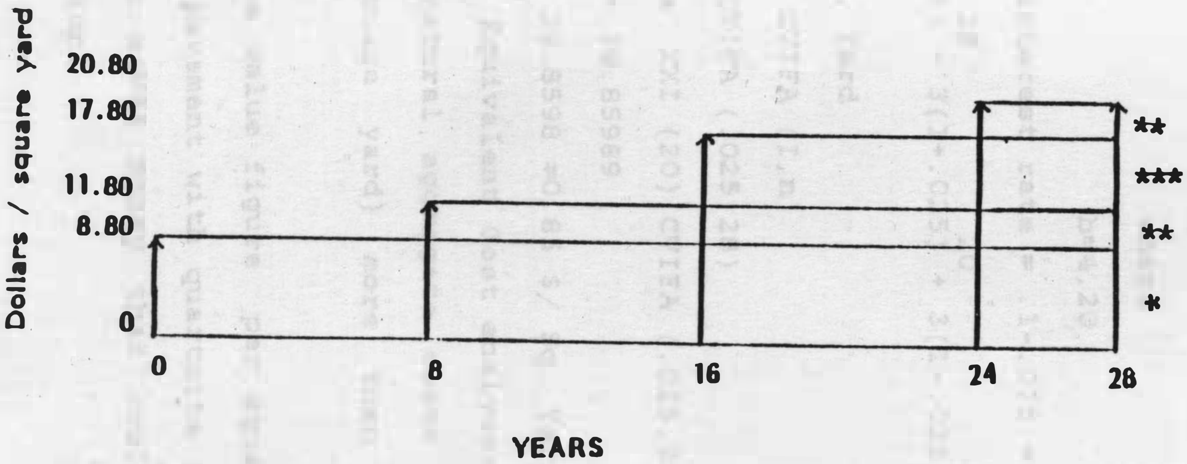
Where from table CVIFA(.025,25) = 34.1578

33.39=AEC * 34.1578

AEC=33.39/34.1578 = .98 $/Sq. yard



Lot 1 : Pavement with natural aggregate



Lot 2 : Pavement with quartzite

LEGEND :

* INITIAL COST

** MAINTENANCE COST

*** OVERLAY COST

Figure 14 : Cost model

In the same way the future value and Equivalent Annual Value for an asphalt mat constructed with quartzite (dollars/square yard) for a life span of 28 years is calculated as follows:

FVQZ=Future value of quartzite surface

$$= C2(1+I)^{n} + \Sigma\ Y4(1+I)^{b} + Y6(1+I)^{d}$$

where n=28; where b=4,20; where d=12

where I = Real interest rate = .1-.075 = .025

$$FVQZ= 8.8(1+.025)^{28} + 3(1+.025)^{20} + 3(1+.025)^{4} + 6(1+.025)^{12}$$

=33.87 \$/Sq. Yard

FVQZ= AEC * CVIFA (I,n)

33.87=AEC * CVIFA (.025,28)

Where from table XXI (20) CVIFA (.025,28)=39.8598

33.87= AEC * 39.85989

AEC= 33.87/ 39.8598 =0.85 \$/ Sq. Yard

The Annual Equivalent Cost analyses show that the pavement with natural aggregate costs 0.98 - 0.85 = .13(dollars/ square yard) more than pavement with quartzite.

This is the value figure per square yard of the pavement. The pavement with quartzite is economically preferable. It saves money that could be spent on other construction.

For example, a parking lot similar to the one infront of the Animal Science building that has an area of 3535 square yards will amount in saving of 3535 * 0.13 = 459.55 (dollars / year) during one year of its life if quartzite is used instead of natural aggregate.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

A.CONCLUSION

Based on the information gained from this investigation, the following conclusions concerning the performances of quartzite and natural aggregate in flexible pavement as a case study can be drawn:

1. The Marshall method of mix design demonstrated that a natural aggregate requires 13.3 percent more asphalt than quartzite in order to meet design specifications.
2. The raw data with a temperature effect correction for skid resistance was measured in the two parking lots by the British Portable Skid Resistance Tester. These data were then analyzed using the Statistical Analysis System. The following were noted:
   a) The mean skid number at the entrance / exit of the parking lot with quartzite was highly significantly greater than the skid number at the entrance / exit of the parking lot with natural aggregate.
   b) At driveways, manholes and parking places,the mean skid number was higher,although not

significantly,for the the parking lot with quartzite than for the parking lot with natural aggregate .

c) The Minnesota and South Dakota Departments of Transportation, clearly show that quartzite pavement has a higher skid resistance than pavements with natural aggregate .

It could be concluded that a pavement with quartzite gives a higher skid resistance

3. The economic studies were conducted on the bases of future value and then annual equivalent cost analysis. The annual equivalent cost analysis showed that pavement with quartzite saved 0.13 dollars per square yard, which is a 15.3% saving over natural aggregate. It was concluded that quartzite pavement is economically preferable to pavement with natural aggregate.

The clear conclusion found in this research is that quartzite pavement is preferable in the long run to natural aggregate.

B. RECOMMENDED AREAS FOR FUTURE STUDIES

Considering the analysis of the data and the resulting conclusions presented in this investigation ,it is recommended that this study be pursued in the future to find the long term effects of traffic on the surface textures of both parking lots.

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